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Design of Patch Antenna for Multiband Operation Using Metamaterial

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Abstract: The design of microstrip patch antenna has been suggested and simulated to resonate at multiband frequency for wireless communications- Bluetooth (2.4 GHz), WiMax (3.3 GHz) and Wi-Fi (5 GHz) respectively. The proposed antenna has been modeled with FR4 substrate that has a dielectric constant of 4.4 and thickness of 1.6 mm to operate with 3 GHz. A unit of CSRR is designed to operate at 3 GHz. The array of unit cell is implemented on the patch of 4 x 5 array. The dimension of split in the split ring is optimized to yield the better resonance at the desired frequencies. The proposed antenna model is simulated using the High Frequency Structure Simulation (HFSS) software which is based on Finite Element Method. The simulated results shows that the proposed antenna provides better performance in terms of VSWR, return loss and good impedance matching.

Keywords- VSWR, Bluetooth, WiMax, WiFi, Radiation Pattern, Input Impedance, Finite Element Method, CSRR, SRR, Metamaterial.

I. Introduction

An antenna is a transducer which converts electrical signal into electromagnetic waves and radiates into the space and vice versa. The microstrip have many useful features like low weight, low profile, light cost and ease integration with PCBs. Besides its advantages, it has some disadvantages, one of the major is narrow bandwidth. The microstrip antennas have been used in many applications-Satellite Communications, Remote Sensing, Biomedical etc.,. The new generations of cellular telephones integrate several communication systems at once such as DCS, GSM, UMTS, Wi-Fi standards, WiMax etc., which makes the need of a microstrip patch antennas to operate multiple frequencies.

The metamaterials (MTMs) are defined as artificial effective homogeneous EM structures with unusual properties that are not available in nature. An effective homogeneous structure is a structure that should have a structural average size of the cell (p) to be much smaller than the wavelength of the guide λ_g.

$$\text{ie.} \quad \lambda_g > p \tag{1}$$

Metamaterials are the artificial structures designed to exhibit peculiar electromagnetic properties not commonly found in nature. Metamaterials with negative permeability (μ) and permittivity (ε), are called as left-handed materials.

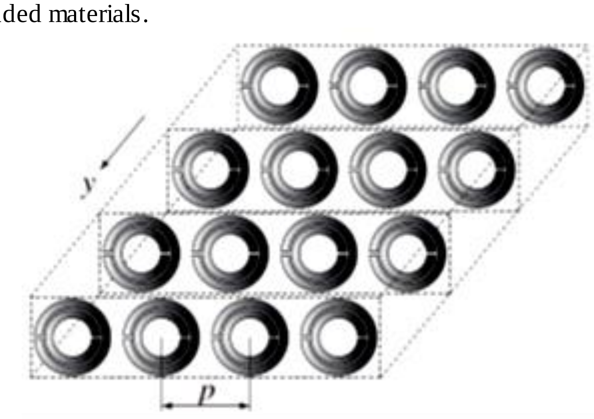


Fig. 1: Metamaterial with Array of SRRs

The single band patch antenna can be modified into multiband antenna. In the proposed system, first the single unit cell of CSRR is designed. Then, array of unit cells were etched on the patch, which acts as metamaterial to yield multiple frequency.

A. *Working of Patch Antenna:*

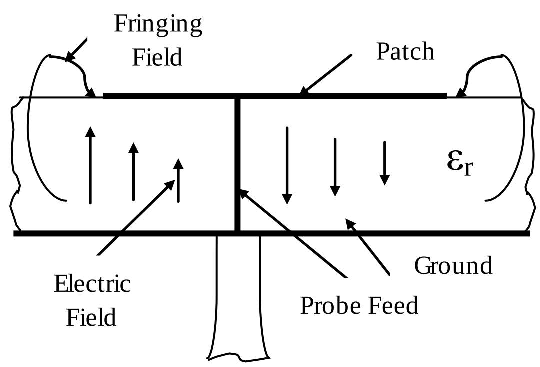


Fig. 2: Probe Feed Patch Antenna

The figure 2 gives a patch antenna composed of a substrate with one side patch and another side a ground plane. The center conductor of a coax acts as a feed probe used to couple EM energy in and out of the patch [7]. At the patch centre, the E-field will be zero, high (+ve) on the one side and low (-ve) at another side, and. Since it is

a cavity, the E-field does not stop at the edge of the patch; rather, it extend the outer edge. These extensions of the field are called as fringing fields and these makes the patch to radiate.

II. LITERATURE SURVEY

S.Raghavan and Anoop Jayaram [1] proposed "Metamaterial Loaded Wideband Patch Antenna". It discussed a new design technique to a wide band microstrip patch antenna. The wideband was achieved by implementing complementary square split ring resonators with the inset feed. Artificial Neural Network was used to optimize the dimensions of the complementary SSRR. The Split ring resonator is etched at the two corners of the patch where feed is given to antenna. The bandwidth of the antenna was improved and provided good efficiency but by compromising the gain.

Amir. Bazrkar et al [2] proposed, "Miniaturization of Rectangular Patch Antennas partially loaded with μ-Negative Metamaterials". It describes a partially loaded rectangular patch antenna by a metamaterial which operate as μ–negative metamaterials (MNG). The parameters like radiation pattern and return loss of the conventional rectangular patch antenna and the μ-Negative Metamaterials loaded Patch antenna are measured. The antenna that was to be operated at 6.35 GHz made to operate at 1.73 GHz. Thus, the antenna size was reduced by 77%.

Raoul o. Ouedraogo et al [3] proposed "Miniaturization of patch antennas using a Metamaterial-inspired technique". It introduced a new methodology to miniature the circular microstrip patch antenna. The complementary split-ring resonator was placed between the ground plane and the patch horizontally. The miniaturization of the patch antenna is accompanied with decrease in the antenna efficiency and bandwidth.

Sridhar E. Mendhe and Yogeswar Prasad Kosta [4] proposed "Metamaterial Properties and Applications. The paper discussed the research activities of metamaterial in various fields and properties of the metamaterial. The functions of electromagnetic response that can offer exciting possibilities of future design of components and devices were reviewed.

Y.Xie, L.Li, C.Zhu and C.Liang [5] proposed "A novel dual-band patch antenna with complementary split ring resonators embedded in the ground plane". It has presented a novel design for microstrip patch antenna to operate at dual frequency with complementary split ring resonators (CSRRs). Three CSRR were etched in the conventional patch antenna ground plane to yield the dual frequency. The antenna showed good performance at both the frequencies with major contribution at first operating frequency and minor contribution at second operating frequency. The size of dual band patch antenna is also reduced.

Mahdy Rahman Chowdhury Mahdy et al [6] proposed "An Idea of Additional Modified Modes in Rectangular Patch Antennas Loaded with Metamaterial". It has proposed a rectangular patch antenna loaded with a metamaterial for producing an additional modified mode(s). They proposed antenna gave better radiation performance by introducing modified modes for interface resonance mode. The rectangular patch antenna operates at dual frequency and the miniaturization of the patch antenna is also achieved.

Yoonjae Lee and Yang Hao [8] proposed "Characterization of Microstrip Patch Antennas on Metamaterial Substrates loaded with complementary Split-Ring Resonators". It described the characteristics of microstrip patch antenna with a metamaterial loaded substrate. The antenna utilizes CSRR loaded in the ground plane altering the effective medium parameters of the substrate. It presented the comparison of impedence bandwidth of the microstrip antenna on conventional high permittivity substrate and with CSRR loaded substrate and also the proposed antenna improved the bandwidth and the size of the antenna is reduced.

S.Arslangic, T.V.Hansen et al [9] proposed "A review of the S-parameter extraction method with clarification of ambiguity issues in relation to metamaterial homogenization". It has described the extraction method for the S-parameter of metamaterial and material parameter such as permittivity and permeability. The method is proved through an investigation of an incident of a uniform plane wave normally in free-space on planar slab.

III. Proposed Method

The Rectangular Patch Antenna is designed for 3 GHz with the predetermined formula. Then, a unit cell of CSRR is designed for 3 GHz and array of CSRR which acts as metamaterial were introduced in the patch to yield the desired frequencies.

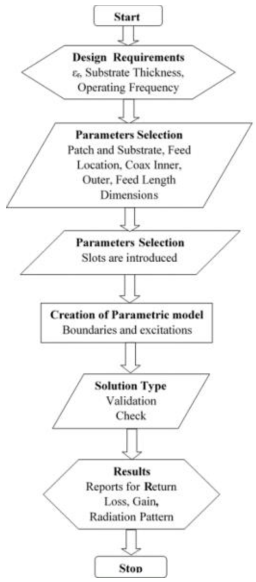


Fig.3: Flow for steps involved in designing the proposed antenna

A. Design Steps For Patch Antenna [10]

1. Operating Frequency, f_o = 3 GHz
2. The substrate material used is FR4. $\varepsilon_r = 4.4$
3. Height of the substrate, h = 1.6mm
4. Wavelength, $\lambda = \frac{c}{f} = \frac{3x10^8}{2(3x10^9)}$ =100mm
5. Effective dielectric constant:

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+\frac{12h}{W}\right]^{-0.5},\ 1< 4.0876 < \varepsilon_r = 4.031$$

6. Width of the patch:

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{3x10^8}{2(3x10^9)}\sqrt{\frac{2}{4.4+1}} = 30.429\text{mm}$$

7. Length extension, $\Delta l = 0.412h\left[\frac{4.0311+0.3}{4.0311-0.258}\right]\left[\frac{w/h+0.264}{w/h+0.8}\right]$ = 0.736 mm

8. Effective length, $L_{eff} = \frac{c}{2fo\sqrt{\varepsilon eff}}$ = 24.903mm

9. Actual length of patch, $L = L_{eff} - 2\,\Delta l$ = 22.83 mm

10. Design of ground plane and substrate:

L_g = 6h+L = 6(1.6) + 22.83 = 45.66 mm

W_g = 6h+W = 6(1.6) + 30.429 = 60.86 mm

11. Coaxial cable:
Inner coax = 0.5 mm
Outer coax = 2 mm

12. Height of the airbox = $\frac{\lambda}{4} = \frac{1/10}{4}$ = 25mm

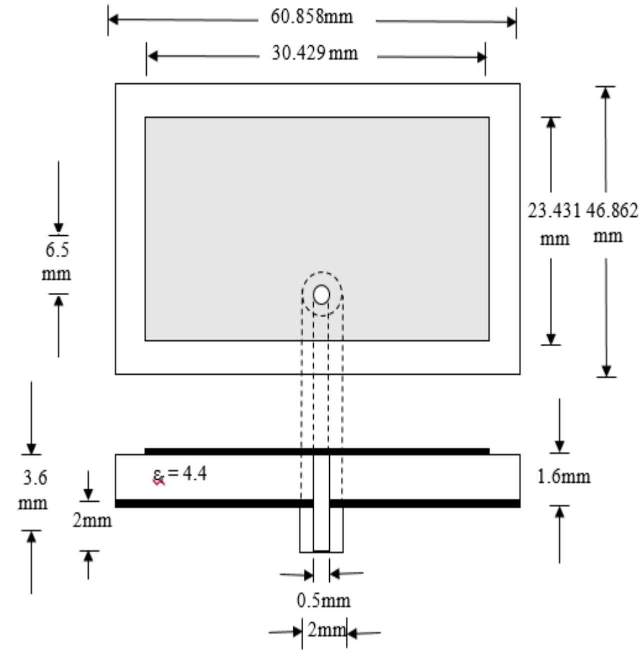


Fig.4: Dimensions of the Patch Antenna

B. Design of Unit Cell of CSRR [11]

The complementary split ring resonator is modeled as Shunt LC resonator tank. The orthogonal electric field excite the CSRR. It is comparable to an electric dipole which is placed along the axis of the ring. Since a dipole generates wave propagating along the ring surface plane, for radiation it relies on the edges of the patch. The coupling between the patch and CSRR comes from capacitance coupling through the ring slot and the split of the outer ring produces magnetic coupling.

a = 5.1 mm; s = w= 0.2 mm;

g =1 mm; N=2

$$\rho = \frac{(N-1)(w+s)}{[L_s-(N-1)(w+s)]} = 0.021\text{ mm}$$

$$L_{savg} = 4[L_s - (N\text{-}1)\ (w+s)] = 19.2\text{ mm}$$

$$L = \frac{\mu_o}{2}\frac{L_{savg}}{4} \text{ x } 4.86\left[\ln\left(\frac{0.98}{\rho}\right) + 1.84\rho\right] = 56.3\text{ nH}$$

$$C = \varepsilon_o\frac{N-1}{2} \text{ x } [2L_s - (2N-1)(w+s)]\ \frac{K\sqrt{1-k^2}}{K(k)} = 0.0512\text{ pF}$$

$$f_o = \frac{1}{2\pi\sqrt{LC}} = 3\text{ GHz}$$

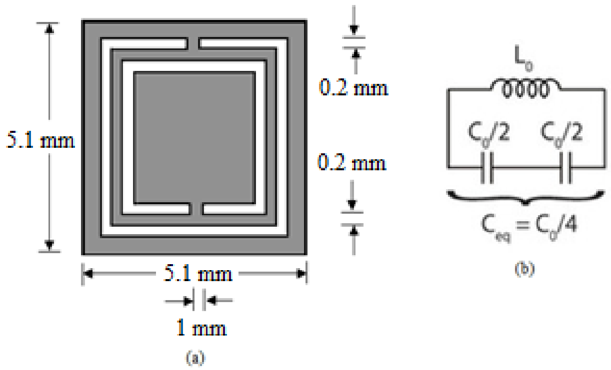


Fig.5: (a) Dimensions of the unit cell of a Metamaterial
(b) Equivalent of the CSRR

The figure 5 shows the dimensions of unit cell of a Metamaterial for 3GHz. The dimensions includes length, thickness of the split ring and gap of the split and the equivalent circuit for the unit cell of CSRR. The length, thickness of the split ring plays an important role in the evaluation of inductance and capacitance, which further determines the frequency.

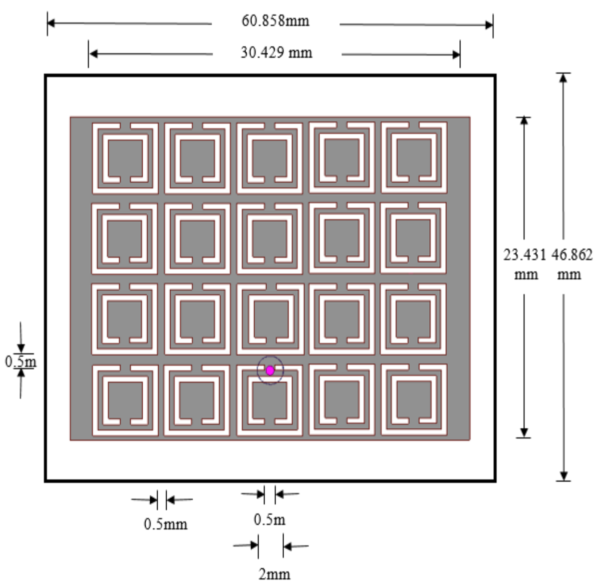


Fig.6: Dimensions of the Patch Antenna loaded with Metamaterial

The figure 6 shows the patch antenna loaded with metamaterial. The unit cell of CSRR are etched on the patch and forms array of it.

IV. RESULTS AND DISCUSSIONS

The figure 7 shows the 3-D HFSS model of a rectangular probe fed patch antenna to operate at 3 GHz.

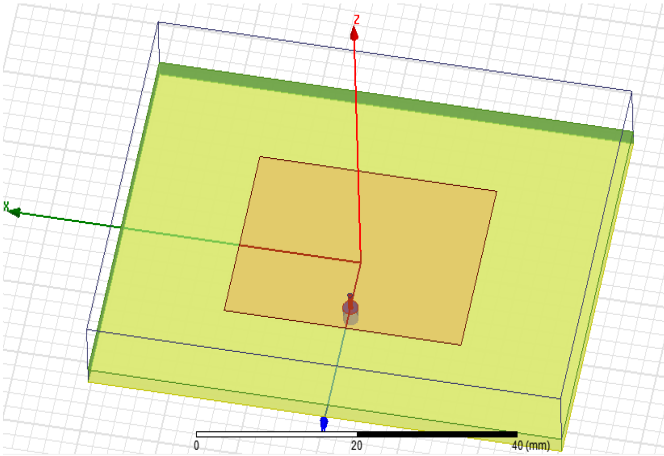


Fig.7: Model of Patch Antenna for 3 GHz

The figure 8 presents the return loss of the patch antenna. The patch antenna resonates at 3GHz at return loss of -40.6379 db. The antenna gives the bandwidth of 174 MHz.

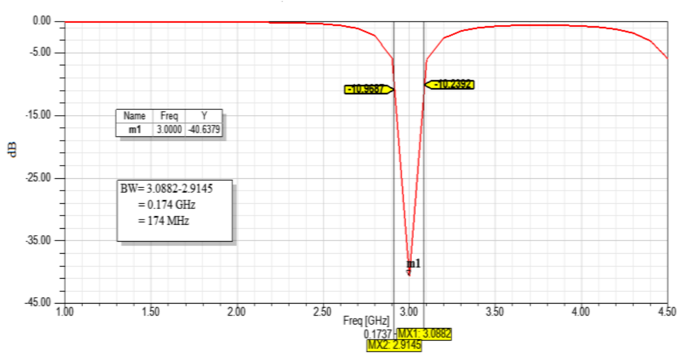


Fig.8: Return Loss at 3 GHz

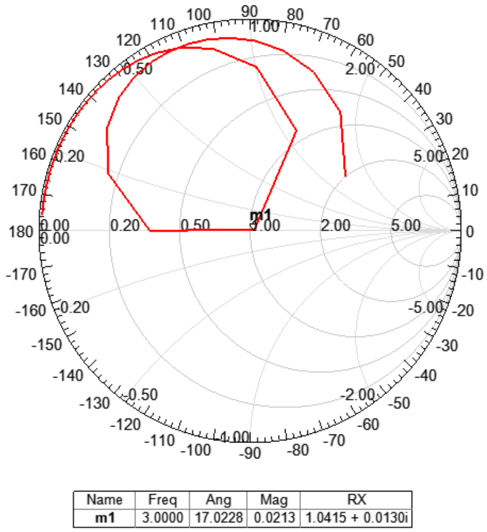


Fig. 9 Smith Chart of a Patch Antenna for 3GHz

The figure 9 shows the Smith Chart for 3 GHz patch Antenna in which the impedence of the antenna is 1.0415Ω. The smith chart is normalized to 50 Ω, thus it is matched with the characteristic impedence of 50 Ω.

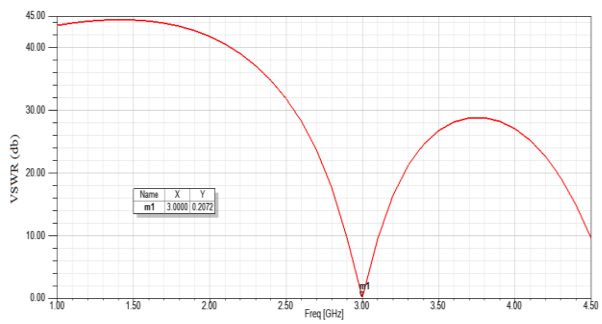


Fig.10: VSWR for 3 GHz patch Antenna

The figure 10 shows the VSWR for 3 GHz patch Antenna at 0.2072 which concludes that the reflection coefficient approximates to zero and atmost the signal is transmitted at 3 GHz.

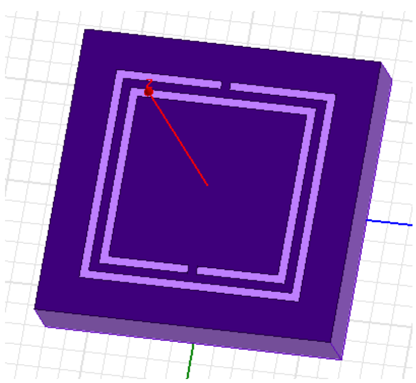


Fig.11: Unit Cell of Metamaterial

The figure 11 shows the unit cell of metamaterial in which it is excited by electric field along z-axis and magnetic field along x-axis.

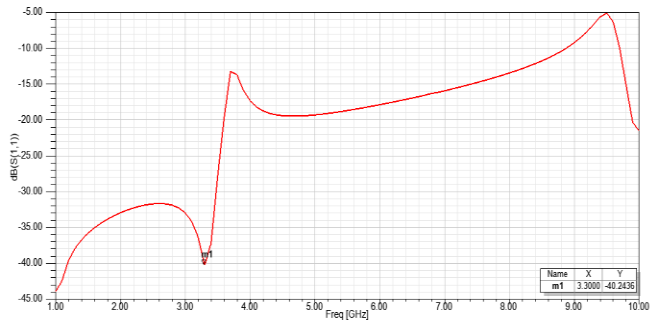


Fig.12: S_{11} Parameter for unit cell of Metamaterial

The figure 12 shows the S_{11} Parameter for unit cell of Metamaterial which resonates approximately at 3 GHz.

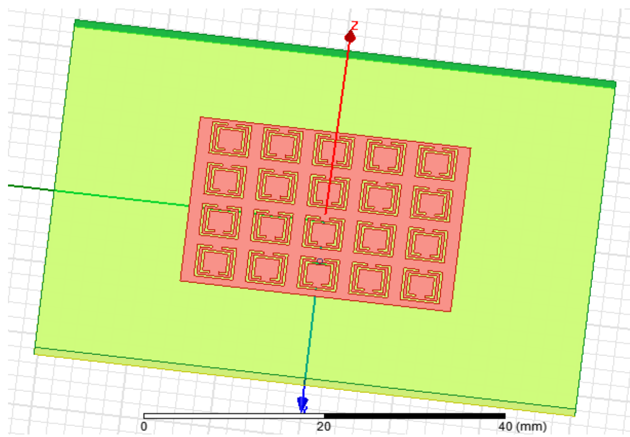


Fig.13: Model of Patch Antenna loaded with Metamaterial

The figure 13 shows the 3-D Model of Patch Antenna with Metamaterial.

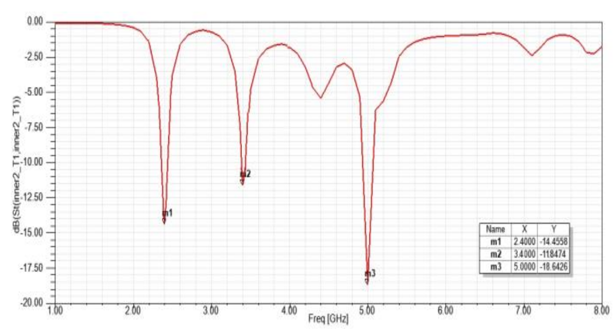


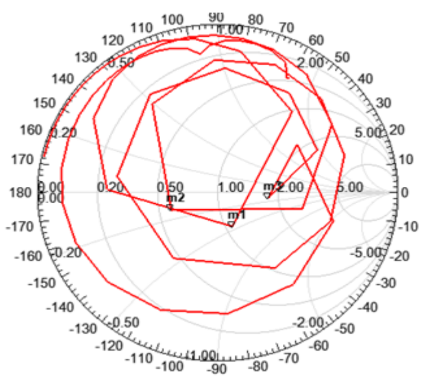
Fig.14: Return Loss of a patch antenna with MTM

The figure 14 presents the return loss of the patch antenna with metamaterial. The split gap of the split ring resonator is optimized by varying from 0.4 mm to 1 mm. As the gap increases, the return loss decreases.

Table 1: Return Loss and Bandwidth of patch antenna loaded with Metamaterial

Resonant Frequency (GHz)	**Return Loss (dB)**	**Bandwidth (MHz)**
2.4	-14.4558	54
3.3	-11.8474	37
5.0	-18.6426	74

The table 1 shows the return loss and Bandwidth of the multiband of a patch antenna loaded with Metamaterial.



Name	Freq	Ang	Mag	RX
m1	2.4000	-68.0658	0.2159	1.0769 - 0.4524i
m2	3.4000	-158.0350	0.2773	1.5801 - 0.1304i
m3	5.0000	-5.9834	0.2840	1.7826 - 0.1148i

Fig.15: Smith Chart for Patch Antenna using MTM

The figure 15 shows the Smith Chart for metamaterial loaded patch antenna in which the impedence for the 2.4 GHz is 1.0731Ω, for 3.3 GHz is 1.5801 Ω and for 5GHz is 1.7826 Ω. The smith chart is normalized to 50 Ω, thus the proposed is matched with the characteristic impedence of 50 Ω.

V. CONCLUSION

The design suggested for a multiband microstrip patch antenna for different wireless communication systems such as Bluetooth, WiMax and WiFi applications was made and simulated. The dimensions of ground plane for the multiband patch antenna were 0.6086 λ x 0.4566λ and the dimensions of the patch were 0.3043 λ x 0.2283λ. The antenna operates/ resonates at the frequency of 3 GHz with the return loss of -40dB and bandwidth of 174 MHz ie) 5%. Then, the unit cell of CSRR was designed for the frequency of 3GHz with the dimensions of 0.051 λ x 0.051 λ. These unit cells were etched on the patch and forms an array of 4 x 5 to act as metamaterial. The Metamaterial implemented using CSRR made the antenna to resonate at 2.3 GHz, 3.3 GHz, and 5 GHz respectively with the bandwidth of 3%, 2% and 4% respectively and provides good matching.

REFERENCES

[1] S.Raghavan and Anoop "Metamaterial Loaded Wideband Patch Antenna" Jayaram, PIERS Proceedings, Taipei, March 25-28, 2013.

[2] Amir. Bazrkar, Azita. Gudarzi and Masoud. Mahzoon "Miniaturization of Rectangular Patch Antennas partially loaded with μ-Negative Metamaterials, International Conference on Electronics, Biomedical Engineering and its Applications (ICEBEA'2012) Jan. 7-8, 2012.

[3] Raoul o. Ouedraogo, Edward j. Rothwell, Alejandro r. Diaz, Kazuko fuchi, and Andrew temme, "Miniaturization of patch antennas using a Metamaterial-inspired technique", IEEE transactions on antennas and propagation, vol. 60, no. 5, May 2012.

[4] Sridhar E. Mendhe and Yogeswar Prasad Kosta "Metamaterial Properties and Applications", International Journal of Information Technology and Knowledge Management, Jan 2011, Volume 4, No. 1, pp. 85-89.

[5] Y.Xie, L.Li, C.Zhu and C.Liang, "A novel dual-band patch antenna with complementary split ring resonators embedded in the ground plane", Progress In Electromagnetics Research Letters, Vol.25, 117-126, 2011.

[6] Mahdy Rahman Chowdhury Mahdy, Md. Rashedul Alam Zuboraj, Abdullah Al Noman Ovi, and Md. Abdul Matin, "An Idea of Additional Modified Modes in Rectangular Patch Antennas Loaded with Metamaterial", IEEE antennas and wireless propagation letters, vol. 10, 2011.

[7] D. Orban and G.J.K. Moernaut, "The Basics of Patch Antennas", edition of the RF Globalnet newsletter, September 29, 2009.

[8] Yoonjae Lee and Yang Hao, "Characterization of Microstrip Patch Antennas on Metamaterial Substrates loaded with complementary Split-Ring Resonators", Microwave and Optical Technology Letters, Vol.50, No.5, 2008

[9] S.Arslangic, T.V.Hansen et.al. , "A review of the scattering parameter extraction method with clarification of ambiguity issues in relation to metamaterial homogenization", Microwave and Optical Technology Letters, Vol.25, No.2, 2007

[10] Balanis, Constantine,"Antenna theory-Analysis and Design", John Wiley & Sons Ltd, Reprinted 1997.

[11] MA Matin, "Handbook of Research on Progressive Trends in Wireless Communications and Networking", February, 2014